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Project Summary

Effects of Planform Geometry on Tidal Flushing and Mixing in Marinas

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R. E. Nece, E. P. Richey, J. Rhee, and H. N. Smith

Physical models for rectangular marinas were tested to determine how various geometric designs affect tidal flushing and internal circulation in small harbors. The models were scaled to have surface areas, water depths, and tide ranges comparable to prototype marinas in the Pacific Northwest. Various geometric parameters were investigated and results were presented in terms of average tidal flushing coefficients and by contour drawings of equal exchange coefficients. Emphasis was placed on planform geometry and aspect ratio, the two variables which designers have the most control over when designing a marina. The report shows that the optimal flushing and internal circulation occurs when the basin length to width ratio lies between 0.5 and 2.0, the corners are rounded, and the single entrance is centrally located in the breakwater on the seaward side of the harbor.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Procedures

This research focuses primarily on the relative exchange of water due to tidal flushing of the marina basin. Tidal flushing characteristics are expressed in terms of an "exchange coefficient." The laboratory tests were conducted in an 8 x 12 foot basin 18 inches in depth. Constant period tides were produced by a tide generator. Tide ranges, water levels, and tidal periods could be adjusted to simulate a variety of real-world situations. A photo densitometer was used to measure dye concentrations. Photos were taken by a camera mounted approximately 7 feet above the center of the marina basin. Dye density values were measured directly from 35 mm black-and-white negatives.

All experiments were conducted on model marina basins of the same planform area and same uniform depth at mean tide. The variables included tide range, entrance width, entrance location(s), and the rounding of interior corners of the rectangular basin.

The equivalent "prototype" dimensions were as follows. The planform area was 1.25×10^6 square feet (2.97 acres). This is larger than the area of most Pacific Northwest marinas, but is exceeded by some. On the basis of the limited boat density values described by other investigators, the "prototype" tested could accommodate approximately 1,000 boats. The mean depth within the basin was 16 feet, taken at mean water level. The three tide ranges used were: neap, 3 feet; mean, 6 feet; spring, 12 feet. These values are repre-

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sentative of marinas in the Pacific Northwest and in Puget Sound in particular. The range of aspect ratio used in the tests varied from 0.21 to 4.80, more than spanning the usual range found in small-boat basins with single entrances aligned with one side wall. A single 250-foot radius was selected to investigate effects of rounding the interior corners of the rectangular basin. The three entrance widths were 125, 250, and 500 feet. Results of tests using a variety of variables are represented graphically in the final technical report.

Conclusions

The conclusions apply only to the hydraulic, or tidal flushing, performance of the marina. Tidal exchange in itself is not an index of water quality, although in general as the exchange improves, the quality of the water within the basin approaches that of ambient water. In judging the water quality of a marina, relative rather than absolute standards should be employed because water quality in the marina cannot exceed that of the exterior water with which it exchanges.

Comparisons presented of different planform geometries are based on results for the 6-foot tide range. From a design standpoint, this particular value was chosen because it is typical of mean ranges in the Pacific Northwest.

1. *Planform geometry of aspect ratio.* The study confirmed earlier conclusions of other investigators that for basin length (L)/basin width (B) less than 1/3 and L/B greater than 3, multiple circulation cells (gyres) exist in rectangular basins with single asymmetric entrances. When multiple cells exist, the gross exchange decreases and spatial variability of local exchange increases.

When a single gyre exists, the exchange is lower in the center of the basin than it is near much of the perimeter, due to the residual circulation when the gyre is established. This may be a positive result from a fisheries standpoint, as juvenile migrant salmon that reside temporarily in marinas tend to remain in the relatively shallower water near the basin perimeter where local exchanges may be greater than the gross exchange for the basin.

The oval-shaped marina with an asymmetric entrance that has become popular in the Pacific Northwest, produces a single-gyre circulation pattern and good overall flushing performance. Since this study indicates the exchange would tend to be greater than the average around the perimeter, such oval basins should be favorable from a fish-protection standpoint.

2. *Ratio of entrance cross-sectional area, a, to basin planform area, A.* The range of discrete entrance widths, w, from 125 feet to 500 feet provides a four-fold variation in a/A, but for a constant tidal range, A, the differences in the spatial average per-cycle exchange coefficient, E, are no larger between the various curves of w = constant than they are between various L/B ratios for the same w. Because such wide variations in performance do occur for a/A and H constant as planform geometry varies, it is concluded that the a/A ratio is not a governing factor.

3. *Effect of rounding of corners in the basin interior.* Rounding of interior corners apparently has little effect on overall flushing, but it has been qualified that the rounding of corners does indeed produce a greater uniformity in local exchange throughout the basin. "Hot spots" of poor local exchange are mostly eliminated.

4. *Orientation and location of single entrances.* On the basis of the limited experiments performed, it appears that a single center entrance results in better flushing than does a single corner-related asymmetric entrance. This result was obtained for rectangular, square-corner basins only; presumably, the same result would hold for basins with rounded corners. This result can be attributed partially to the fact that the jet entering the basin on the flood tide is able to circumnavigate a greater length of basin perimeter than it could in a basin with an asymmetric entrance, all other geometric parameters being the same.

One precautioning statement must be made. In the experimental program, the entrance was designed so that the flood tide inflow entered as a uniform flow in a direction normal to the other face of the marina. In a more typical field situation, the entrance would more likely be a gap in a breakwater. Consequently, in the presence of longshore currents, the inflow would enter the basin with some momentum parallel to the shoreline and, therefore, the flow patterns in the basin would not possess the symmetry sought in the laboratory tests. However, the results of a previous theoretical study by another investigator (D. R. Askren), indicate that for circulation induced in basins by a steady, non-tidal longshore current past entrances in frontal breakwaters, a central location was the optimum site for a single entrance. Thus, the two sets of results, obtained for different boundary conditions, lead to the same conclusion.

The experimental data, in particular the exchange contours, show that for an elongated basin with a single asymmetric entrance the uniformity of flushing, and in particular the exchange in the innermost part of the basin, is better when L/B is less than 1 than it is when L/B is greater than 1. Again, this behavior can be linked to the penetration distance of the inflow jet. The recommendation with respect to design criteria is that when a basin is elongated (say, with an aspect ratio exceeding an absolute value of 2.0) and a single asymmetric entrance is used, the entrance should be aligned so that the inflow direction is parallel to the long axis of the basin.

5. *Effects of two entrances versus a single entrance.* Results are quite limited. In general, two-entrance basins would be very sensitive to the effects of persistent longshore currents which were deliberately avoided in the laboratory experiments. Short-circuiting could exist if the longshore currents are primarily unidirectional. Generalizations are dangerous for multi-entrance basins because the interior circulation patterns are sensitive to local head levels which result from the physical configurations of the entrance and near-shore and longshore current patterns. However, on the basis of the limited results, it appears that more uniform flushing is obtained when the entrances are of equal, or at least comparable, width.

On the basis of the results presented, although the particular configuration was not tested, the test design for a rectangular basin for optimum tidal flushing would incorporate an aspect ratio L/B between 0.5 and 2.0, rounded corners, and a center entrance. Asymmetric entrance basins within the same L/B range also possessed satisfactory flushing action, particularly those with rounded corners. As noted, these results would indicate that basins with oval planform and an asymmetric entrance, such as have been built and/or proposed at a limited number of sites in the Pacific Northwest, should possess satisfactory exchange characteristics.

This study provides guided estimates, but not precise values of gross flushing

coefficients for various harbor planforms having entrance coefficients comparable to those tested. Center entrances not normal to the outer face of the marina still should be investigated because they would produce at least two equal gyres within the basin.

R. E. Nece, E. P. Richey, J. Rhee, and H. N. Smith are with the Department of Civil Engineering, University of Washington, Seattle, WA 98195.
***Richard J. Callaway** is the EPA Project Officer (see below).*
The complete report, entitled "Effects of Planform Geometry on Tidal Flushing and Mixing in Marinas," (Order No. PB 81-219 537; Cost: $9.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Environmental Research Laboratory
U.S. Environmental Protection Agency
200 S.W. 35th Street
Corvallis, OR 97330

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